

# TOWARD A MODEL FOR HFQPOS IN MICROQUASARS

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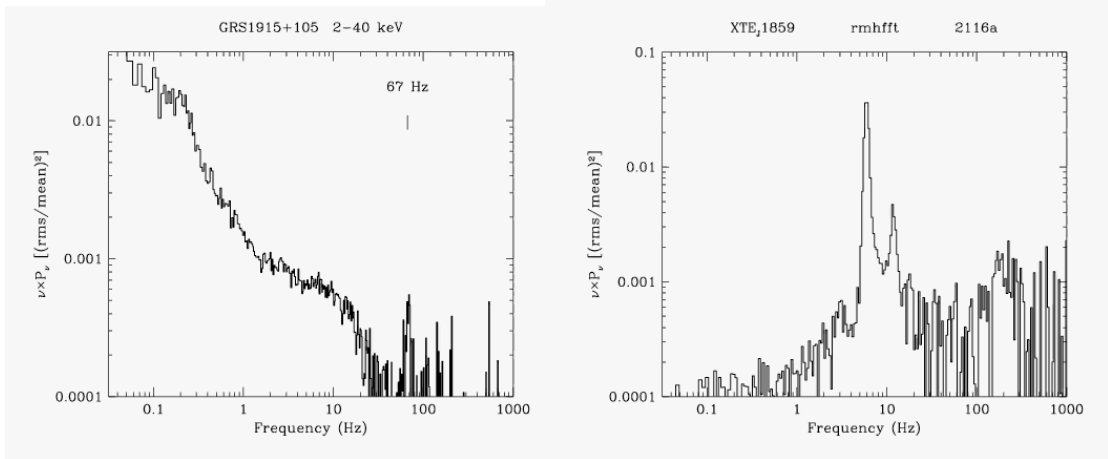
**Abstract.** There have been a long string of efforts to understand the source of the variability observed in microquasars but no model has yet gained wide acceptance, especially concerning the elusive High-Frequency Quasi-Periodic Oscillation (HFQPO). We first list the constraints arising from observations and how that translates for an HFQPO model. Then we present how a model based on having the Rossby Wave Instability (RWI) active in the disk could answer those constraints.

Keywords: microquasars

## 1 What does a HFQPO model need to explain

Even if High-Frequency Quasi-Periodic Oscillations are much weaker than their Low-Frequency counterparts we now have data from several outbursts from eight different sources. Indeed, sources like XTE J1550-564, have exhibited HFQPOs with enough regularity to obtain a stringent list of constraints for any theoretical model wishing to provide an explanation for them [3].

- The first observational fact that one needs to explain is the **modulation of the flux** associated with the frequency. Indeed, even if HFQPO has a rms amplitude much lower than in the case of the LFQPO, the flux still modulates at a level of a few percent and it has been shown to be stronger at higher energies (see [3] for examples).
- Since the observation of the 67Hz HFQPO of GRS 1915+105 we know that HFQPOs can occur in



**Fig. 1. Left:** Power density spectrum (PDS) of GRS 1915+105 showing the 67Hz. **Right:** PDS of XTE J1859+226 with LFQPO and HFQPO.

the absence of LFQPOs. It is therefore required that the HFQPO model be independent of the LFQPO model.

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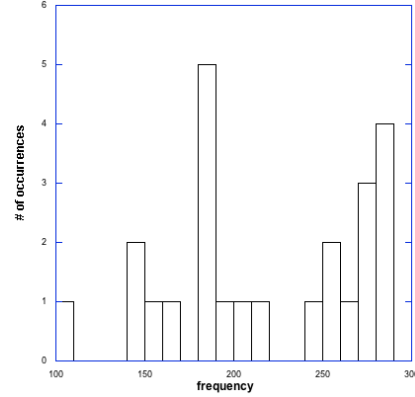
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However, most HFQPO detections do occur in the presence of a LFQPO, as observed for example during the outbursts of XTE J1550-564 or XTE J1859+226. When they co-exist we have type A and B LFQPOs, not the standard type C.

All of this demonstrates that, even if **HFQPO and LFQPO models need to be independent, they also need to be coherent with each other as the two QPOs co-exist in the disk**. This is a more stringent requirement than it may at first seem, as one need not only find a model for the HFQPO's characteristics, but also a model that can coexist in a disk with an LFQPO.

- Another exacting requirement coming from observation is the fact that the frequencies of HFQPOs, albeit more stable than in the case of the LFQPO, show a small but significant variation. In the case of XTE J1550-564 the figure on the right represents the observed occurrences of the HFQPOs in 10Hz bins during the outburst of 1998-99 and 2001.

**Any model aiming to explain the HFQPOs must be able to reproduce the observed dispersion in the frequency.**

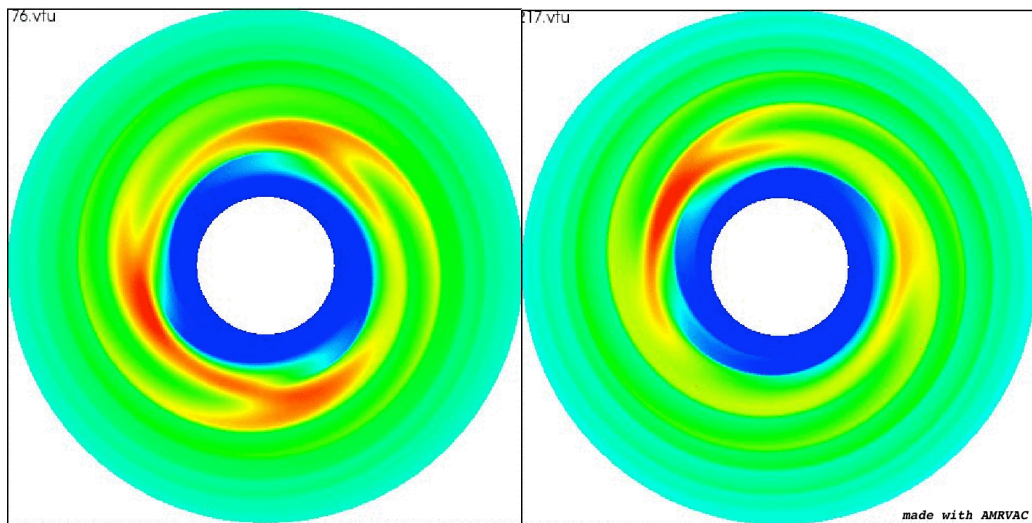


- Another characteristic of HFQPOs is that they can be observed either alone **or** in 'pairs' (with closely related frequencies, most of the time near a 2:3 ratio). **This points toward a mechanism that can select several linked frequencies depending on the disk conditions.**

Any model wishing to explain HFQPOs must be able to explain this small but stringent list of requirements. As we get more observations with future detectors we will be able to add to this list and further constrain the models.

## 2 The Rossby Wave Instability as a model for HFQPOs

The Rossby Wave Instability is an hydrodynamical instability that occurs in the presence of an extremum of the vortensity (defined by  $\Sigma\Omega/(2\kappa^2) \cdot p/\sigma^\gamma$  where  $\kappa$  is the disk epicyclic frequency,  $\Omega$  is the rotation frequency and  $\sigma$  is the surface density). Because of its characteristics, we proposed the RWI as a possible explanation for HFQPOs [4].



**Fig. 2.** Density slab of the disk from an hydrodynamic simulation of the RWI at two different times, using the code AMRVAC

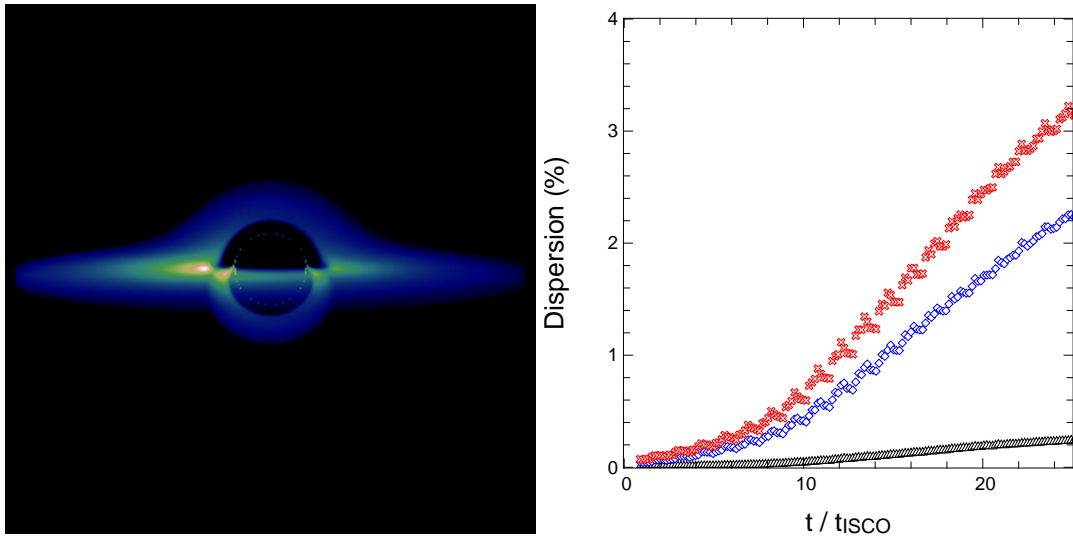
- In the case of a disk in which the inner edge approaches its last stable orbit an extremum of the vortensity becomes possible therefore leading to the RWI as shown in the hydrodynamic simulation shown on Fig.2. These graphs represent a slab ( $z = 0$ ) of the density in a 3D disk in the Paczynsky & Wiita (1980) gravitational potential, which means a spin  $a = 0$ . We later used modified Newtonian potential [1] to model the full range of spin and confirmed the results.

Because the inner edge of the disk must be close to its last stable orbit but not ‘exactly’ at it, there is a small radial range where the instability can develop [4] leading to a change in observed frequency. As we do not know precisely the density profile in the disk, especially close to its last stable orbit, it is hard to put a hard boundary on the frequency changes but it could reach 30% without a dramatic change to the profiles.

- Another interesting point is that the RWI does not require the disk to be in the condition for a LFQPO model to occur [4]. Nevertheless, the RWI was also demonstrated to be stronger in the presence of a vertical magnetic field[4] and we have recently shown the ability of the RWI and the AEI (a candidate to explain the LFQPO) to co-exist in a magnetized accretion disk [5,6]. Therefore, it could give rise to either HFQPOs alone or HFQPOs and LFQPOs depending on the disk condition, as is observed.

- From numerical simulation, we also found that, depending on the disk conditions, the dominant mode can be  $m = 3, m = 2$ , (see Fig.2) more rarely  $m = 1$ , or a mix of these[4] which fit well with the observed characteristics of HFQPOs.

- We now perform 3D simulations of the RWI and confirm the previous 2D and analytical results and also produce the associated image(see Fig.3)/light curve using the code Gyoto [7].



**Fig. 3.** Left: Ray tracing of a 3D simulations of the RWI at  $85^\circ$  inclination. Right: time evolution of the rms of the flux modulation at  $85^\circ$ ,  $45^\circ$  and  $5^\circ$  inclination.

When the RWI is active in the disk the light curve is modulated up to a few % [8] and this modulation is energy dependent. The precise impact of the spin, especially the case of high spin, is still under study, but the RWI is present and modulate the flux

### 3 Conclusions

The RWI is a promising model for HFQPOs as it gives rise to several observed features such as the possibility to have small variations in the frequencies as well as mode selection depending on the conditions in the disk. Moreover, this instability can co-exist with the Accretion-Ejection Instability [5,6] proposed as a model for the ubiquitous LFQPO. Lastly, we have recently shown that this instability can effectively modulate the X-ray flux within the observed limit [8]. In the future, we will explore the impact of the spin of the black hole, the link with ejection and the overall evolution of the system.

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